Report of MQX – Cryostat Conceptual Design Review
Conducted on 3 December 1998

Introduction and Summary

This Conceptual Design Review is the first of a series of design reviews involving the MQX cryostat to ensure the adequacy of the engineering design prior to the start of fabrication. For a system to pass the CDR, it must be demonstrated that the engineering design is feasible and that an adequate R&D program has been planned to develop and prove the design.

FNAL is responsible for the cryostats for the IR Interaction Region Quadrupole systems. The FNAL work scope includes:

- Design, development and fabrication of the cryostats.
- Construction of a full-scale model heat exchanger.
- R&D on support structures.
- Construction of a cryostat for the full-scale prototype quadrupole.
- Assembly of U.S.- and Japanese-built quadrupoles together with intermediate beam absorbers, and CERN-supplied correction coils and instrumentation into the cryostats to produce complete units for all four interaction regions.
- Design and fabrication of the intermediate beam absorbers.

The design review committee members are: P. Pfund, FNAL, Chair, J. Strait, FNAL, R. Ostojic, CERN, R. van Weelderen, CERN, L. Williams, CERN, P. Sacre, CERN, S. Plate, BNL, T. Peterson, FNAL, and J. Zbasnik, LBNL

The following items were covered during the review:

- Design of the mechanical support of the magnet cold mass in the cryostat.
- Plan for testing of the mechanical support.
- Plans for testing of the model heat exchanger.
- Planned R&D activities.
- Structural, alignment, and thermal design criteria.
- Cryogenic pipe sizes, pressures, and flows.
- Interconnect component positions and physical parameters.
- Milestone dates for specification of cryostat interfaces.

The following items are listed in the CDR charge but were not covered during the review. They will need to be addressed in other reviews:

- Design features to accommodate either a MQXA (KEK) or MQXB (US) cold mass in the cryostat.
- Design of the heat exchanger located within the cryostat.

- Functional Specification and Interface Specification documents that are being prepared which together define the requirements to be met by the design.
- Methods of assembly of several magnets to form a single cold mass to be inserted into the cryostat.

Committee Recommendations

The committee recommended that the work go forward from conceptual to detailed design. The next review is an Engineering Design Review (EDR) of the MQX, scheduled for completion by December 1999. The committee recognized that the EDR deadline may be difficult to meet due to some unresolved issues, the present workload, and available manpower. The US LHC Accelerator Project Management should be made aware of this.

The committee did not get a clear description of the responsibilities associated with integration of subsystems in the cryostat, i.e. KEK cold masses, FNAL cold masses, correctors, cryogenics, buses, instrumentation, etc. Some of these responsibilities are assumed by the cryostat designer and some by the IR System Design/Integration task. The committee recommended that project management review the distribution of responsibilities to ensure that all the subsystems are covered and that the cryostat designer is not assuming more than appropriate. The committee felt that this would also help resolve the manpower shortage on the cryostat.

The committee identified several issues that needed to be addressed after this conceptual design review. The issues are listed in two categories: I. Issues Affecting the Concept and II. Issues Affecting Details of the Design. The committee requested that the designers address the issues in category I immediately while the issues in category II can be addressed as required to support the detailed design.

I. Issues affecting the concept

1) Heat Loads

The committee felt the thermal performance of the spider support was not sufficiently justified and documented. Based on the presented heat loads, there is a definite conflict between the design performance of the external heat exchanger and the heat loads given during the review. Based on estimates of the planned LHC refrigeration capacity, the committee felt the 40 W per triplet static head load at 1.9K was too high by a factor of 2. The 170 W heat load assumed by the designer at 50-70K was also felt to be too high. The zero dynamic heat load at 4.5-20K was believed to be 21 W even without the addition of the need to cool the absorbers at 4.5K. The dynamic heat load at 1.9K, given as 150 W, was believed by the committee to be 162 W. These values need to be verified and incorporated in the design.

Action: Verify that the estimated heat loads to the 1.9 K level are within the design parameters of the heat exchanger for "nominal" conditions (corresponding to the operating temperature of the magnets of = 1.93 K), with an appropriate reserve for "ultimate" cryogenic conditions. The estimated loads should include loads due to the support structure, radiation from warmer surfaces, lambda-plates and dynamic load during beam operation. The estimated loads should take into account the possibility that KEK quads, because of their larger mass and diameter, have slightly higher static and dynamic loads.

Action: Reduce as much as is reasonably possible the heat loads on the 1.9 K, 4.5-20 K and 50-70K levels. Document the heat loads required for all thermal intercepts and their respective sources.

Action: CERN should provide estimates of the available refrigeration capacities for each temperature level at each IR. The cryostat designer should confirm that the estimated heat loads are within those capacities.

2) Q2a – Q2b Connection

The slot length allocated for the Q2a – Q2b connection is the tightest in the triplet. There was concern among the committee that the interconnect might take a significant part of the available 1.0 m space. Information on the required slot length needs to be transmitted to CERN promptly in order to determine the final MCBX length. The interconnect lengths in other slots, which influence the bellows design, position of the cryostat reinforcements, TAS2 and TAS3 length, etc., also need to be verified.

Action: Expedite the detailed design of the Q2a – Q2b interconnection. Document the interconnect length required.

Action: Complete the detailed design of the Q1 – Q2, Q2 – Q3, and Q3 – DFBX interconnections. Document the interconnect lengths required.

3) Stresses on the Supports

Mechanical testing is planned to evaluate the supports under simulated transport and operational loads. The committee felt the test should also simulate the effects of thermal cycling. In addition, the combined effect of radiation damage, static stress and thermal cycling should be addressed.

Action: Perform tests on the cold mass support simulating mechanical stresses during transport and operations, including thermal stresses. Confirm the stability of the supports after repeated thermal cycles and ageing following irradiation.

4) Alignment Tolerances of the Cryostat

There was considerable discussion on the alignment requirements that the cryostated magnets have to meet. No definitive number was be available, nor was an estimate presented for the alignment accuracy using the spider supports.

Action: The support system should be analysed for accuracy and stability of alignment of the cold masses with respect to the cryostat fiducials during the design life of the machine. The results should be compared with the requirements defined by CERN and US-LHC.

5) Method of Inserting Cold Masses

A clear concept has not yet been developed to insert cold masses into the cryostat when the spider is the preferred support design. The feasibility of a mechanical support design depends on a feasible insertion concept. There appears to be limited clearance between the four connection points on the spider and the inside of the vacuum tank. The combination of the geometry of the disk-like spider, the limited clearances and any non-uniformity in ovality of the cryostat down its length could make the design of an insertion tool extremely complicated.

Action: Expedite development of a concept for inserting cold masses into the cryostat.

6) TAS2 and TAS3

Currently TAS2 and TAS3 are believed to be cylindrical in shape and made of copper. Their approximate lengths and inner diameters and ranges of outer diameters have been estimated. These components can be heavy (as much as 700 lb in the case of TAS3) and their method of attachment in the triplet could affect the cryostat design. Currently the conceptual design makes no allowance for either active or passive cooling of TAS2 or TAS3. The committee believes that active cooling with supercritical He between 4.5-20 K and at 3 bar is necessary to alleviate the heat load at 1.9 K.

Action: The system designer should initiate the necessary calculations to develop the detailed design of TAS2 and TAS3, specifically their lengths, diameters, and material of construction.

Action: Incorporate active cooling of TAS2 and TAS3 with supercritical He between 4.5-20 K and at 3 bar into the design of the cryostat.

Action: Proceed with the design of the support system taking into account the weights of TAS2 and TAS3 and minimizing the effect of their load on the deflection of the cold masses.

7) *Interconnect Seals*

The cold line seals in the magnet test facility will be mechanical while the seals in the LHC will be welded. The design needs to be able to adapt to both installations. CERN has a design for this type of application. The committee felt the default design should be to use elastomer seals except where they are specifically prohibited or are functionally inadequate.

Action: The design should allow the connection at the magnet test facility through mechanical seals and final installation through welded seals.

Action: Evaluate the CERN design for possible use in the MQX cryostat.

Action: Consider the use of elastomer seals except where they are specifically prohibited or are functionally inadequate.

II. Issues Affecting Details of the Design

1) *Cold Mass and Cryostat Interfaces*

The conceptual design assumes that the cryostat will have to accommodate two types of cold masses that have different diameters and weights in an end plate-to-end plate configuration. The design also assumes that the cryostat designer will have to provide end domes for each type of magnet.

Action: Document the interface specifications between the cryostat and cold masses for both FNAL and KEK cold masses.

2) *Buswork*

The committee felt it was not clear who is responsible for providing buswork for the KEK cold masses.

Action: Specify whether buswork for the KEK cold masses will be supplied by KEK, the U. S. Project or CERN.

3) *Radiation Environment at the Interconnects*

The radiation environment at the interconnects is not fully documented.

Action: Obtain radiation predictions at the interconnects.

4) *Phase Separator*

The location of a phase separator was unclear for locations where the DFBX is downhill from the MQX. There may not be room in the cryostat and the default assumption appears to be that it should be placed in the DFBX. The FNAL system designer has estimated the required volume.

Action: Work with the FNAL system designer and the LBNL DFBX engineer to determine the size and location of phase separator.

5) He II Liquid Supply Line

The He II liquid supply line could be located either inside or outside of the heat exchanger. The final position needs to be identified.

Action: Identify whether the liquid supply line will be located inside or outside of the heat exchanger.

6) Volume of Cold Mass LHe

The volume of LHe in the KEK and FNAL cold masses was not certain. Significantly different volumes could effect the piping in the cryostat.

Action: Consider the effect of the volume of LHe in the FNAL and KEK cold masses on cryostat piping design.

7) Vacuum Loads

The design feature for accommodating forces due to vacuum loads has not been determined.

Action: Determine the design scheme to react the vacuum loads.

8) Shipping and Handling Loads

There was some uncertainty about the appropriate design loads due to shipping and handling.

Action: Obtain recognized data on shipping (general and specific) and handling loads, and assess their applicability. Constraints for shipping need to be included in the early stage of the optimization of the supports.

9) Cryostat FMEA

The committee asked about the failure modes and off-normal conditions that the cryostat might be expected to experience. It was stated that a Failure Modes and Effects Analysis (FMEA) would be performed. The committee felt that the conditions analyzed by CERN should also be considered (e.g. a LHe leak into the vacuum space).

Action: Perform a Cryostat FMEA. Obtain and apply CERN FMEA scenarios to the analysis.

10) Vacuum Conductance

There was concern that the plate-like design concept of the spider may limit conductance of the vacuum axially.

Action: Evaluate the conductance of the vacuum axially due to the presence of the spider.

Appendix A
Conceptual Design Review – Charge
IR Quadrupole Cryostat

Background:

FNAL is responsible for the cryostats for the IR Interaction Region Quadrupole systems. The FNAL work scope includes:

- Design, development and fabrication of the cryostats.
- Construction of a full-scale model heat exchanger.
- R&D on support structures.
- Construction of a cryostat for the full-scale prototype quadrupole.
- Assembly of U.S.- and Japanese-built quadrupoles together with intermediate beam absorbers, and CERN-supplied correction coils and instrumentation into the cryostats to produce complete units for all four interaction regions.
- Design and fabrication of the intermediate beam absorbers.

Planned Design Reviews:

This Conceptual Design Review is the first of a series of design reviews to ensure the adequacy of the engineering design prior to the start of fabrication. These reviews will also address the proper functioning and integration of the components into the LHC, the budget impact of the procurement or fabrication method proposed, the schedule and the program plan. The CDR is generally conducted once the basic engineering design has been established. For a system to pass the CDR, it must be demonstrated that the engineering design is feasible and that an adequate R&D program has been planned to develop and prove the design.

This CDR will be following by at least two other major design reviews, the Engineering Design Review (EDR) and the Production Readiness Review (PDR). The EDR will be conducted when most of the R&D is complete and the engineering design has been finalized. For a system to pass the EDR, it must be demonstrated that all of the technical and engineering challenges have been adequately addressed allowing the design and purchase of parts and tooling for full-scale prototypes and production deliverables to proceed. The PRR will occur after final proof-of-design is complete, i.e., after prototypes are delivered and tested successfully, etc. It will occur before the final production of the deliverables for the LHC. The PRR must include a strategy for fabrication or procurement, quality assurance, and a component test plan.

Design Team:

The design will be represented by:

- T. Nicol, FNAL Cryostat Lead
- J. Kerby, FNAL Project Manager
- A. Zlobin, FNAL IR Quad WBS Level 3 Manager

Appendix A
Conceptual Design Review – Charge
IR Quadrupole Cryostat

Design Review Committee:

The design review committee members are as follows:
- P. Pfund, FNAL, Chair
- J. Strait, FNAL
- R. Ostojic, CERN
- R. van Weelderen, CERN
- L. Williams, CERN
- P. Sacre, CERN
- S. Plate, BNL
- T. Peterson, FNAL
- J. Zbasnik, LBNL

Scope of the Review:

The review will cover the following items in particular:
- Design of the mechanical support of the magnet cold mass in the cryostat.
- Design features to accommodate either a MQXA (KEK) or MQXB (US) cold mass in the cryostat.
- Design of the heat exchanger located within the cryostat.
- Plans for model testing.
- Functional Specification and Interface Specification documents that are being prepared which together define the requirements to be met by the design.

The design review committee has the usual freedom to investigate other areas of the cryostat design that present a risk to the successful completion of the project, installation, and operation in the LHC.

Timing of the Review:

The review is scheduled for Thursday, December 3, 1998 at Fermilab. It is anticipated to take one day.

Results of the Review:

This review is a Level-3 project milestone, scheduled for completion by December 15, 1998. The review is complete with the issuing of a report summarizing the technical designs reviewed, committee recommendations, and action items.

Appendix B
US LHC MQX Cryostat Conceptual Design Review
Fermilab – ICB 2E December 3, 1998

CDR Agenda – IR Quadrupole Cryostat

8:30 am	Design Review Committee Planning Session (committee only)
9:00 am	Introduction to the CDR: P. A. Pfund
9:05 am	Introduction to the Design: J. Kerby
9:15 am	Presentation and Discussion of Design: T. Nicol
12:00 pm	Lunch
1:00 pm	Design Review Committee Planning Session (committee only)
1:30 pm	Design Review Committee Working Session (with designers)
3:30 pm	Design Review Wrap-up, Reviewers and Presenters
4:00 pm	Adjourn

Designers	Reviewers	Observers
J. Kerby	P. A. Pfund, Chairman	B. Strauss, DOE
A. Zlobin	J. B. Strait	M. Lamm, FNAL
T. Nicol	R. Ostojic, CERN	
	R. van Weelderen, CERN	
	L. Williams, CERN	
	P. Sacre, CERN	
	S. Plate, BNL	
	T. Peterson, FNAL	
	J. Zbasnik, LBNL	

CDR Schedule – IR Quadrupole Cryostat

11/3/98	Contents of Preview Package Selected
11/13/98	Preview Package Sent to Design Reviewers
11/24/98	Reviewer Preliminary Comments Returned to Chairman
12/3/98	Design Review Meeting Conducted
12/8/98	CDR Report Draft Circulated
12/11/98	Reviewer Comments Returned to Chairman
12/15/98	Final Review Report Issued